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Isotopic evidence for dietary diversity at the mediaeval Islamic necropolis of Can Fonoll (10th to 13th centuries AD), Ibiza, Spain

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Abstract

The diet of the population interred at the Islamic necropolis of Can Fonoll, Ibiza, Spain, which was in use between the 10th and 13th centuries AD, is reconstructed from the carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratios of bone collagen from 112 individuals. The mean±sd(1σ) $\delta^{13}C$ (–19.0±1.3‰) and $\delta^{15}N$ (10.3±0.8‰) values of the Can Fonoll population indicate a diet based largely on terrestrial C_3 resources. However, the wide range of both $\delta^{13}C$ (–20.6‰ to –8.6‰) and $\delta^{15}N$ (7.0‰ to 12.1‰) values attested at Can Fonoll indicate significant variation in individual diet. The elevated $\delta^{13}C$ values of a small proportion of the individuals buried at Can Fonoll are consistent with the consumption of a large proportion of, or dependence on, C_4 resources, such as millet. Comparison of the $\delta^{13}C$ and $\delta^{15}N$ values of the Can Fonoll population with those of other mediaeval populations from the Balearic Islands and mainland Spain highlights a wide range of stable isotope values, which reflects not only significant differences in diet but also points to widespread mobility within the Mediterranean Basin.

Key Words: C_4, Ibiza, Islamic, Millet, Stable Isotopes

INTRODUCTION

The Spanish island of Ibiza, part of the Balearic Islands in the Western Mediterranean has seen an influx of peoples from the eastern and central Mediterranean (in particular North Africa) since at least the mid-7th century BC (McMillan and Boone 1999; O'Connor 2003). In the 8th century AD the Iberian Peninsula came under Moorish influence, which resulted in linguistic, social, economic, technological, cultural and religious change (McMillan and Boone 1999). There is evidence that Islamic influence in Ibiza started at least in the 8th or 9th centuries and the island was under Islamic control certainly from the 10th century until 1235 with the Christian conquest by the Crown of Aragon (Davies 2014; Gurrea Barricarte and Martín Parrilla 2016).

Fuller et al. (2010) investigated the impact of cultural change on diet, one aspect of cultural behaviour through which identity may be expressed. Diet was reconstructed through carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope analysis of human bone collagen of archaeological Ibizan populations. This study suggested that there was a significant shift in diet associated with Moorish expansion into Ibiza. The Islamic population from the early mediaeval necropolis of Es Soto, in Ibiza town, which was in use from the 10th to the 13th centuries, exhibited a greater reliance on C_4 resources than earlier populations on Ibiza (Fuller et al. 2010; Nehlich et al. 2012). However, Ibiza town was an important centre for trade and the diet of the Es Soto population may not be representative of populations elsewhere on the island.

Here, we present the results of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope analyses of a contemporaneous Islamic population from a necropolis located at Can Fonoll in the southwestern region of Ibiza (Figure 1 and Figure 2). Those interred in the cemetery (*maqbara*) may have been involved in agricultural production on the island (Castro 2009) and likely represent a more residentially stable community than that of Ibiza town. The Can Fonoll assemblage represents one of the largest mediaeval Islamic populations from Ibiza to be studied to date (Kyriakou et al. 2012). Comparison with the urban population at Es Soto (Fuller et al. 2010) and other mediaeval populations from the Iberian Peninsula offers a broader understanding of dietary variability within the Balearic Islands and beyond.

Figure 1. Location of Can Fonoll, Ibiza, Spain.

Figure 2. Photograph of excavated graves at Can Fonoll necropolis (© Jonathan Castro Orellana and Joan Roig). [about here]

RECONSTRUCTING DIET

The Balearic Islands witnessed a population influx from mainland Al Andalus following the establishment of Islamic control in the early 10th century (Kirchner 2009a). Thirteenth-century records detailing land rents in rural areas of Ibiza indicate small groups of settlements and associated farmland, with names of Arabic-Berber derivation (Kirchner 2009b). Watermills, constructed to irrigate small allotments on valley floors, were also used to grind cereals into flour (Kirchner 2009b). While it is known that intense agriculture and irrigation took place, direct evidence for the diets of mediaeval Ibizans is limited.

By comparison, Islamic period agricultural practices, cultivars, and diets on mainland Spain are relatively well attested. Agricultural intensification is evident: use of fertilizers, such as ash and straw, was widespread (Bolens 1978). Systems of irrigated terraces were constructed to support exotic, introduced crops such as sugarcane and citrus fruits (Watson 1983; Puy and Balbo 2013). However, the primary importance of cereals is underscored by an abundance of naked wheat and hulled barley in archaeobotanical assemblages, while oil-bearing plants and nuts are also evident (Bolens 1978; Alonso Martinez 2005; Alonso et al. 2014). Historical accounts of diet in medieval Spain support the prominence of cereals and other plant foods in diet: wheat, sorghum and millet, fruits and olives were all described as important staples (García-Sánchez 1996, 2002; Constable 2013). Pulses such as lentils and chickpeas, were reported to have been widely consumed, particularly by those of lower status (García-Sánchez 2002). The meat of goat, sheep and chicken, as well as milk, cheese, butter and eggs were also important components of the Islamic diet (Grewe 1981; García-Sánchez 2002; O'Connor 2003; Constable 2013). Textual evidence further indicates that in the mediaeval period Muslims abstained from wine, shellfish, pork and lard, as well as the meats of other animals that were not prepared according to Islamic law (Constable 2013).

However, historical records provide a limited overview of mediaeval diet, often describing foods consumed by elites with little mention of the habits of individuals of lower status, or alternatively, focussing on religious restrictions on foods and eating practices (Bolens 1978;

Grewe 1981; Constable 2013). Additionally, information on the relative importance of foodstuffs is often contradictory (cf. O'Connor 2003; Constable 2013; Burns 2015).

Stable Isotope Analysis

In contrast to historical sources, $\delta^{13}C$ and $\delta^{15}N$ stable isotope ratio analysis of human remains can determine population level dietary intake and highlight individual variations in diet (Katzenberg 2000; Lee-Thorp 2008; Reitsema 2013). Carbon and nitrogen stable isotope ratios of bone collagen are reliable indicators of long-term (mainly) dietary protein intake in a protein adequate diet (e.g. van der Merwe and Vogel 1978; Sealy et al. 1987; Sealy 2001; Müldner and Richards 2007; Schoeninger 2010; Fuller et al. 2012a; Commendador et al. 2013; Quintelier et al. 2014).

Plants in different environments (terrestrial [i.e. C_3 vs C_4], marine and freshwater) fix/acquire carbon during photosynthesis in different ways. Plants utilised as dietary staples generally fix carbon by one of two pathways, either the C_3 or C_4 pathway (DeNiro and Epstein, 1978; Krueger and Sullivan, 1984; Ambrose and Norr, 1993). C_3 plants comprise most grasses and plants native to temperate regions, including oats, barley, wheat, and also rice. C_4 plants include important cereal staples such as maize and millet. C_3 plants generally have more depleted ^{13}C values than C_4 plants. For example, a typical consumer of foods drawn from the terrestrial C_3 food web would have $\delta^{13}C$ values between approximately –20‰ and –18‰, while a consumer entirely dependent on resources from the C_4 food web would be expected to have $\delta^{13}C$ around –7.5‰ (cf. van der Merwe and Vogel 1978; Tykot 2004). Marine plants also fix carbon by the C_3 pathway. However, the $\delta^{13}C$ values of marine plants are distinctive from those of terrestrial C_3 plants because marine carbon isotope ratios are enriched relative to atmospheric carbon isotope ratios (Tykot 2004). A typical consumer of predominantly marine resources might have isotope values of $\delta^{13}C$ = –12‰. Although this overlaps with the carbon isotope values of C_4 consumers, the two dietary components can often be distinguished by $\delta^{15}N$ analysis.

It is widely accepted that nitrogen stable isotopes are enriched with each trophic level by c. 3–5‰ (Bocherens and Drucker 2003) and potentially by up to 6‰ (O'Connell et al. 2012; Iacumin et al. 2014). Human consumers of terrestrial resources will typically have $\delta^{15}N$ values c. 6–10‰, but results can be variable due to differing environmental conditions and anthropogenic activities such as manuring (Tykot 2004; Lee-Thorp 2008; Fraser et al. 2011; Bogaard et al. 2013). Marine/freshwater food-chains are generally longer than terrestrial food-chains so consumers of aquatic resources tend to have higher $\delta^{15}N$ values than consumers of terrestrial resources (although see Hedges and Reynard [2007] for discussion of uncertainties in the $\delta^{15}N$ trophic shift). This $\delta^{15}N$ difference between terrestrial and aquatic food-chains *generally* allows diets based on marine resources to be distinguished from those derived from the C_4 food web.

Thus, co-analysis of $\delta^{13}C$ and $\delta^{15}N$ isotope values can potentially distinguish between diets based on terrestrial C_3 and C_4 plant food web, freshwater and marine resources, and identify the trophic level of the consumer (e.g. Chisholm et al. 1982; Schoeninger and DeNiro 1984; Schwarcz and Schoeninger 2011). However, caution must be exercised in the interpretation of stable isotope results. A range of non-dietary factors can affect an individual's stable isotope values, such as pregnancy and disease (Fuller et al. 2005; Olsen et al. 2014). Furthermore, determining the relative contribution of plant vs animal protein in diet is complicated by uncertainties in the human-diet $\delta^{15}N$ trophic shift (Hedges and Reynard 2007).

CAN FONOLL – ARCHAEOLOGICAL BACKGROUND

The cemetery at Can Fonoll, near the area of Molí de Can Fonoll in the southwest of Ibiza, was discovered during motorway construction (Castro 2009). Rescue excavations were undertaken between October 2006 and February 2008. Remains of 154 individuals were recovered from 167 burials at Can Fonoll, a large Islamic necropolis (c. 1220 sq. m) or maqbara at the site (Castro 2009; Kyriakou et al. 2012). The burials all follow typical Islamic funerary tradition: graves were oriented SW-NE, individuals laid on their right side and facing SE toward Mecca, and there was a lack of surviving grave goods and headstones (Castro 2009). The cemetery was dated to c. 10th to 13th centuries AD on the basis of the burial practices, and the well-established historical evidence relating to the occupation of Ibiza by Islamic populations (Castro 2009). The human remains generally displayed poor preservation, with a significant degree of surface erosion and bones were highly fragmented (Kyriakou et al. 2012).

The human remains were analysed in 2010 by a team from the University of Edinburgh, UK (Kyriakou et al. 2012). Bioarchaeological data, including demographic information, were collected following the recommendations of Brickley and McKinley (2004) and Buikstra and Ubelaker (1994), and were the focus of a separate publication (Kyriakou et al. 2012). Of the 154 individuals, 112 were adults, 21 were juveniles and 21 had an unknown age at death. Amongst the adults, 23 were females or possibly female and 35 were males or possibly male (Kyriakou et al. 2012).

MATERIALS AND METHOD

Materials

Bone samples (ribs and long bones) for stable isotope analysis were obtained from 143 of the 154 individuals, but only 112 of these yielded well-preserved collagen – these 112 samples are the focus of the current paper. They comprise 85 adults, 13 juveniles and 14 of unknown age (see also Table S1). Amongst the juveniles, one (7.6%) was in the age range 1–5 years, two (15.3%) in the 5–10 year age range, eight (61.5%) between 10 and 15 years and two (15.3%) in the 15–18 year age range.

To investigate diet, human $\delta^{13}C$ and $\delta^{15}N$ values need to be considered alongside the isotope values of potential foods. Ideally, comparisons should be made with animal and plant remains found in association with the human remains. However, no animal or plant remains were recovered from the Can Fonoll necropolis. Comparisons are therefore drawn from the nearby, contemporaneous site of Es Soto, located 4 km away from Can Fonoll, for which $\delta^{13}C$ and $\delta^{15}N$ values have been published (Fuller et al. 2010; the average values of the animal remains sampled are presented in Table 1 and plotted in Figure 3).

Table 1. Mean±sd(1σ) $\delta^{13}C$ and $\delta^{15}N$ values of animal remains from Ibiza, taken from Fuller et al. (2010). [about here]

Figure 3. Mean±sd(1σ) $\delta^{13}C$ and $\delta^{15}N$ values for the Can Fonoll humans. [about here]

Method

Bone collagen was extracted at the Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology (Leipzig, Germany) following the procedure described in Richards and Hedges (1999) with the additional step of ultrafiltration by Brown et al. (1988). Each bone sample (~500 mg) was cleaned by air abrasion and placed in a 0.5 M HCl solution at 4 ºC for ~2 weeks, with acid changes every 2 days. Demineralized samples were gelatinized at 70 ºC in a pH=3 solution for 48 hours. After purification with a 5µm EZEE© filter, the solution was concentrated by Amicon© ultrafilters (<30 kDa), and then was frozen and freeze dried for 2 days. Approximately 0.5 mg of extracted collagen was weighted for carbon and nitrogen analysis, using a Flash EA 2112 coupled to a Delta XP mass spectrometer (Thermo-Finnigan, Bremen, Germany). The results are reported in 'per mil' (‰) relative to the standards VPDB for $\delta^{13}C$ and AIR for $\delta^{15}N$. The analytical precision is ± 0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$. Although the collagen yields are low, ranging from 0.1% to 3.0% (cf. van Klinken 1999), ultrafiltration isolation of well-preserved collagen is indicated by the atomic C:N ratio (Richards et al. 2008). A total of 112 (i.e. 79%) of the 143 individuals produced collagen with acceptable atomic C:N between 2.9–3.6 (DeNiro 1985), and five samples outside this range are omitted from the discussion below (see Table S1).

RESULTS AND DISCUSSION

Diet at Can Fonoll

Carbon and nitrogen stable isotope values for the Can Fonoll population are presented in Table S1 and plotted in Figure 3. The mean±sd(1σ) $\delta^{13}C$ and $\delta^{15}N$ values of the Can Fonoll population ($\delta^{13}C$ = –19.0±1.3‰; $\delta^{15}N$ = 10.3±0.8‰, n=112) are consistent with a diet based primarily on resources from the terrestrial C_3 food web.

The Can Fonoll human isotope values differ from the mediaeval Ibizan domestic herbivore values (mean±sd(1σ) $\delta^{13}C$ = –19.9±0.7‰; $\delta^{15}N$ = 6.9±2.1‰, n=18) published in Fuller et al. (2010). The difference in $\delta^{13}C$ is c. 1‰ and that in $\delta^{15}N$ is 3.4‰. These values suggest that cattle and caprines, and secondary products from these animals, were important components of diet, but that other resources such as plant foods were dietary staples. Dental caries rates of the Can Fonoll population (Kyriakou et al. 2012) supports the consumption of some carbohydrates; caries prevalence is similar to that of other mediaeval sites in the Iberian Peninsula (see Lalueza-Fox and González-Martín 1999) and slightly lower than that of earlier populations in Ibiza (see Márquez-Grant 2006).

Despite the island setting of the Can Fonoll cemetery, marine resources do not appear to have contributed significantly to the diet (suggested by the relatively low mean $\delta^{15}N$ value).

This interpretation is offered cautiously as in the Mediterranean region, identifying the consumption of marine foods is non-trivial (e.g. Prowse et al. 2004; Keenleyside et al. 2006; Craig et al. 2009). The $\delta^{13}C$ and $\delta^{15}N$ values of modern fish caught in the Mediterranean Sea have been observed to vary widely and often have values similar to those of terrestrial foods (see Pinnegar and Polunin 2000, Garvie-Lok 2001; Polunin et al. 2001 and Badalamenti et al. 2002). For example, the mean $\delta^{13}C$ and $\delta^{15}N$ values of fish captured off the southeast coast of

Ibiza were -17.8‰ and 11.3‰ respectively (Polunin et al. 2001). Furthermore, in individuals with relatively low protein diets, nutrient scrambling (Prowse et al. 2004; Craig et al. 2013) may result in carbon and nitrogen being drawn from different dietary constituents – carbon is assimilated from dietary carbohydrates and/or lipids in protein inadequate diets (Hedges 2004). These factors invalidate the notional linear correlation of $\delta^{13}C$ and $\delta^{15}N$ in establishing the consumption of marine resources (see Schoeninger et al. 1990).

Table S1. Demographic information and $\delta^{13}C$ and $\delta^{15}N$ values of the Can Fonoll population. [about here]

Differences in individual diet

The $\delta^{13}C$ and $\delta^{15}N$ values of the Can Fonoll necropolis population exhibit wide ranges, which hint at intra-population differences in dietary intake (cf. DeNiro and Epstein 1978; DeNiro and Schoeninger 1983). Spanning approximately one trophic level, the range of $\delta^{15}N$ values (from 7.0‰ to 12.1‰) of the Can Fonoll population is large and is consistent with differences in individual diets. Two suspected statistical outliers (SPSS boxplot), individuals T-12 and T-122, have relatively low $\delta^{15}N$ values, 8.2‰ and 7.0‰, respectively, compared to the population mean of 10.3‰. Both individuals are adult males. Their $\delta^{13}C$ values, -19.2‰ and -20.0‰, respectively are consistent with a diet based on C_3 resources. These values possibly suggest that there were socio-economic or socio-religious restrictions to the consumption of animal products among the Can Fonoll population. Those individuals with lower $\delta^{15}N$ values likely consumed a greater proportion of plant foods than those with higher values. However, the consumption of legumes, which fix atmospheric N_2 and therefore have low $\delta^{15}N$ values (Szpak et al. 2014), may mask animal protein intake. It is also important to note that non-dietary causes of $\delta^{15}N$ variability cannot be excluded (e.g. Reitsema 2013; Olsen et al. 2014).

The spread of $\delta^{13}C$ values is exceptionally large ranging from –20.6‰ to –8.6‰. Five of the individuals analysed are statistical outliers, with a further three individuals suspected statistical outliers. Four of these individuals (T1, T20, T121 and T122, see Table S1) have $\delta^{13}C$ values that are typical of diets based on C_3 resources. The other four (T-2, T-14, T-99 and T-155, see Table S1) have distinctive $\delta^{13}C$ values, higher than those generally observed for individuals subsisting exclusively on C_3 terrestrial resources. Three of these individuals are firmly identified as males and one, T-155, is tentatively identified as male.

The $\delta^{13}C$ values of T-2, T-14, T-99 and T-155 (–14.2‰, –14.9‰, –15.6‰ and –8.6‰ respectively) indicate that their diets were distinctive from the other individuals interred at Can Fonoll. Notably, the $\delta^{15}N$ values of these individuals (10.3‰, 11.0‰, 10.8‰ and 10.6‰, respectively) are similar to the population mean (i.e. $\delta^{15}N$ = 10.3‰). The parsimonious explanation for the variation in the $\delta^{13}C$ values of these four individuals, with no associated variation in $\delta^{15}N$ values, is the consumption of varying proportions of C_4 resources (cf. Müldner et al. 2011; and see Figure 3).

One explanation for these values potentially reflecting C_4 resources is the consumption of millet. Millet, indigenous to Africa and Asia, was an important C_4 crop cultivated in mediaeval Europe. The reported $\delta^{13}C$ values for modern millet plants range from –10‰ to –12‰ (McGovern et al. 2004; Pechenkina et al. 2005; An et al. 2015). Archaeobotanical remains indicate the presence of broomcorn millet (*Panicum miliaceum*) in Europe from at least the later part of the 4th millennium BC (Lightfoot et al. 2013; Motuzaite-Matuzeviciute et al. 2013), and consumption of millet is evident in the isotope values of later prehistoric and Roman populations throughout Europe (Murray and Schoeninger 1988; Bonsall et al. 2004; Le Huray and Schutkowski 2005; Le Huray and Schutkowski 2005). However, it is generally thought that millet was viewed as a poor quality cereal (e.g. Iacumin et al. 2014), not used in the kitchens of the elite, and often grown as animal fodder (Adamson 2004).

Sugarcane (*Saccharum*), was also cultivated in mediaeval Europe (Galloway 2005). Sugarcane has a low crude protein content (Pate et al. 2002), and is therefore unlikely to have contributed directly to human bone collagen $\delta^{13}C$ in a protein adequate diet (cf. Hedges 2004). Elevated $\delta^{13}C$ values may result indirectly from the consumption of domesticates fed on sugarcane crops or stubble (Alexander et al. 2015). Animal collagen from the Islamic period of Ibiza, analysed by Fuller et al. (2010), show $\delta^{13}C$ values no higher than expected for a diet based on C_3 plants in the Mediterranean region with $\delta^{13}C < –18‰$. Araus et al. (1997) demonstrated that archaeological C_3 cereal grains from Middle Neolithic to Iron Age sites in northeastern and southeastern Spain had $\delta^{13}C$ values ranging from –24.5‰ to –20.3‰ (with average $\delta^{13}C$ = –22.7‰) – thus, there is no evidence for supplementation of domesticate diet in the Islamic period on Ibiza with C_4 crops (i.e. neither with sugarcane nor millet).

There are no published reports of individuals from European sites with $\delta^{13}C$ values as high as the Can Fonoll individual T-155 with $\delta^{13}C$ = –8.6‰ (cf. Lightfoot et al. 2013). Although it is possible that individual T-155 was local to Ibiza and consumed a distinctive diet for reasons relating to health, social status or cultural preference, an alternative and more likely scenario is that individual T-155 spent much of his life elsewhere, in a region where C_4 resources were a dietary staple. Although millet was used widely across Europe in the mediaeval period (e.g. Rösch et al. 1992; Dembińska 1999), it does not appear to have been a significant component of the human diet in many areas. One exception to this was central Europe: documentary sources indicate that millet was one of the most commonly consumed grains in Poland from the early mediaeval period up to the 17th century AD (Dembińska 1999). It is also possible, and more probable given the historical context of Ibiza, that individual T-155 (and arguably all four of the individuals at Can Fonolls with atypical $\delta^{13}C$ values) had migrated to Ibiza from northern or sub-Saharan Africa (cf Márquez-Grant 2005) shortly before death. Determining how recently before death these individuals migrated to Ibiza is complex for two reasons. First, the lack of knowledge of provenance and consequently the baseline isotope values of foods consumed prior to moving to Ibiza: second, the variation in bone collagen turnover rate, which depends on developmental stage (e.g. Tsutaya and Yoneda 2013), sex (e.g. Garnero et al. 1996), parturition (e.g. Naylor et al. 2000), skeletal element sampled (e.g. Manolagas and Jilka 1995), as well as behaviour (e.g. Thorsen et al. 1997).

Few stable isotope studies of northern African groups subsisting largely on C_4 resources have been undertaken – see Loftus et al. (2016) for a review. Analyses of historic farming populations from Kenya, known to have predominantly consumed a mix of C_4 and C_3 cereals in varying proportions, had $\delta^{13}C$ values ranging from –18.0‰ to –7.3‰, while two individuals from west Kenya, who subsisted exclusively on C_4 resources, had $\delta^{13}C$ values of -6.7‰ and -6.3‰ (Ambrose and DeNiro 1986). The remains of many prehistoric agriculturalists from Africa, inferred to have subsisted on C_4-based food webs, have produced high $\delta^{13}C$ values of up to –4.5‰ (see table 2 in Ambrose and DeNiro 1986 and table 4 in Murphy 2011). The differences in diet evident within the Can Fonoll population may reflect the status or the occupations of these individuals, or more likely, indicates residential mobility, which was commonplace in mediaeval Europe (O'Connor 2003).

Age/Sex related differences in diet

The individual variations in diet are not correlated to age nor to sex. A large proportion of younger to middle age adults (18–35 years) were represented; no older adults (i.e. 45+ years) or infants (i.e. < 1 year) were identified amongst the remains (Kyriakou et al. 2012). The average isotope values of the various age categories represented at Can Fonoll were found to be remarkably similar. Adults in the 18–25 years category (n=61) had mean±sd(1σ) $\delta^{13}C$ = –19.0±1.5‰ and $\delta^{15}N$ = 10.3±0.9‰; while those aged 25–35 years (n=23) had mean±sd(1σ) $\delta^{13}C$ = –18.7±1.2‰ and $\delta^{15}N$ = 10.3±0.9‰. Adults aged 35–45 years (n=2) formed too small a sub-set to provide meaningful comparison; however, their values were in keeping with the younger age groups. Thirteen non-adults (≤18 years) were sampled. The distribution of the dataset was determined to be non-normal (Shapiro-Wilk test, p = 0.000 and p = 0.001 for $\delta^{13}C$ and $\delta^{15}N$ respectively) so the null hypothesis, that the adults vs non-adults had the same $\delta^{13}C$ and $\delta^{15}N$ values was evaluated using the non-parametric Mann Whitney U-test. Average non-adult $\delta^{13}C$ = –19.3±0.3‰ and $\delta^{15}N$ = 10.3±0.6‰ values are not statistically different (Mann Whitney U-test, p = 0.159 and p = 0.743 for $\delta^{13}C$ and $\delta^{15}N$, respectively) from the values obtained for the adult (18+ years) population at Can Fonoll.

The dataset of the males and females is not normally distributed (Shapiro-Wilk test, p=0.000, p=0.032 for $\delta^{13}C$ and $\delta^{15}N$, respectively). The mean±sd(1σ) $\delta^{13}C$ and $\delta^{15}N$ values of the males ($\delta^{13}C$ = –18.4±2.3‰; $\delta^{15}N$ = 10.4±0.8‰, n=31) and females ($\delta^{13}C$ = –19.1±0.4‰; $\delta^{15}N$ = 10.4±0.8‰, n=20) at Can Fonoll are not statistically different (Mann Whitney U-test, p = 0.361 and p = 0.953 for $\delta^{13}C$ and $\delta^{15}N$, respectively) indicating that the diets of males and females are broadly similar at the population level.

Comparison to other mediaeval western Mediterranean populations

The data from Can Fonoll add to the growing evidence for heterogeneity in diet between mediaeval populations in the western Iberian Peninsula and the Balearic Islands. The Can Fonoll population have lower mean $\delta^{13}C$ and $\delta^{15}N$ values than the Islamic population from Es Soto (Shapiro Wilk test indicates non-normally distributed data, p = 0.000 and p = 0.002 for $\delta^{13}C$ and $\delta^{15}N$ values respectively; Mann-Whitney U test, p = 0.000 and p = 0.008 for $\delta^{13}C$ and $\delta^{15}N$ values, respectively; see Figure 4 and Table 2). Although possible, it is unlikely that environmental factors account for the distinct $\delta^{13}C$ values given the proximity and contemporaneity of the two sites. This small but significant difference in dietary patterns likely reflects the respective locations of the two sites.

Individuals interred at Es Soto, which is located in Ibiza town, an important urban centre of trade in the mediaeval period, potentially had greater access to imported foodstuffs, as well as marine resources, than their rural counterparts at Can Fonoll. Mean $\delta^{13}C$ values of the farming community at Can Fonoll (as well as the $\delta^{13}C$ values of the herbivores from Es Soto, all of which have $\delta^{13}C > -18‰$) argues against the local cultivation of C_4 cereals. It is also possible that the difference between the two sites relates to the large number of recent migrants to Ibiza at Es Soto with 'remnant' isotope signatures. Nehlich et al. (2012) established that 18 of 20 individuals sampled had $\delta^{34}S$ values outside the local range indicating that they were not native to Ibiza.

The $\delta^{34}S$ analysis of the Can Fonoll population would help to determine whether the differences in isotope signatures of the two populations might be due to differences in the diets of those native to Ibiza or whether these differences reflect the non-local origin of some of those individuals interred at Can Fonoll. A further consideration is temporal variation in dietary patterns. Although the cemeteries at Can Fonoll and Es Soto are roughly contemporaneous, both sites were in use for several hundred years. In the absence of absolute dates for the individuals sampled for stable isotope analysis, it is not possible to determine to what extent the differences in isotope values between the two sites relates to chronological variations in diet.

Table 2. Mean±sd(1σ) bone collagen $\delta^{13}C$ and $\delta^{15}N$ values of human remains from Ibiza and mediaeval populations from the Mediterranean region.

Figure 4. Scatterplot of stable isotope values of key Ibizan and Valencian Spanish mediaeval sites discussed.

. [about here]

As at Can Fonoll, the wide spread of $\delta^{13}C$ (from –19.4‰ to –13.1‰) values evident in the Es Soto population suggested variation in individual diet (Fuller et al. 2010). Nehlich et al. (2012) established, through the co-analysis of bone collagen $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ values, that the Es Soto population was not consuming marine foods. The mean±sd(1σ) $\delta^{34}S$ value of this group is 9.1±2.7‰ (n=20); consumers of marine resources generally have more elevated $\delta^{34}S$ values reflecting that of marine sulphate c. +21‰ (Rees et al. 1978; Richards et al. 2001). Thus, variation of $\delta^{13}C$ values in the Es Soto group likely reflects differential consumption of C_4 foods (Fuller et al. 2010; Nehlich et al. 2012). Individual ES-T18-2 (with $\delta^{13}C = -13.1‰$, $\delta^{15}N = 12.5‰$ and $\delta^{34}S = 10.2‰$) was interpreted as having consumed a significant proportion of C_4 resources (Fuller et al. 2010). In addition, this individual has a $\delta^{34}S$ value that lies outside the local range indicating that ES-T18-2 had migrated to Ibiza (Nehlich et al. 2012). The $\delta^{13}C$ and $\delta^{15}N$ values of this individual are typical of the values of African groups subsisting predominantly by pastoralism with C_4 cereals as well as wild C_3 plants (cf. Ambrose and DeNiro 1986). However, similar carbon and nitrogen isotope values are also evident in later mediaeval populations on mainland Spain at Gandía, Valencia (Alexander et al. 2015).

In general, the diet of early mediaeval Islamic Ibizan populations is dominated by terrestrial C_3 resources. Mediaeval populations from the Basque region as well as in Aragon in northern Spain also had diets of mainly C_3 foods (Mundee 2009; Lubritto et al. 2013; Quirós Castillo 2013). However, within this general pattern there is some variation, which has often been linked to status. At Jaca in Aragon, a small number of individuals (4 of 27 sampled) with atypical $\delta^{13}C$ values likely consumed greater quantities of C_4 foods and may have been non-local (Mundee 2009). High status populations interred at Saint Tirso monastery, Zaballa, and at Treviño Castle have mean $\delta^{13}C$ values consistent with an exclusively C_3 diet. Mean $\delta^{15}N$ values similar to that of carnivores were interpreted as evidence for the importance of animal resources to diet (Lubritto et al. 2013; Quirós Castillo 2013). Lower mean $\delta^{15}N$ and a wider range of $\delta^{13}C$ values, particularly among the middle mediaeval inhabitants at Aistra, indicated that plant foods and to some extent C_4 plant foods likely comprised a higher proportion of diet. The consumption of C_4 cereals was attributed to the lower status of individuals at this rural site (Quirós Castillo 2013). Slightly elevated mean $\delta^{13}C$ at the Santa Maria church cemetery at Zornoztegi suggests that C_4 resources were consumed, probably indirectly, reflecting the use of C_4 grains as feed for domestic fowl (Quirós Castillo 2013).

Among the later mediaeval populations from Gandía and El Raval in Valencia, C_4 resources comprise a more substantial part of diet (cf. Salazar-García et al. 2014, Alexander et al. 2015). While there are slight differences in the diets of Muslims and Christians at two later mediaeval necropoli at Gandía (i.e. Benipeixcar vs Colegiata de Santa Maria), the isotope values of both groups reflect the importance of C_4 plants or C_4-plant consumers to the diet (Alexander et al. 2015). Similarly, at El Raval, a late mediaeval necropolis with a largely Islamic population and a number of *moriscos* (i.e. converts to Christianity), located less than 100 km to the south of Gandía, a mixed terrestrial C_3/C_4 diet is indicated (Salazar-García et al. 2014). Higher mean $\delta^{15}N$ values at El Raval in comparison to those of the Gandía sites points to the greater consumption of fish (Shapiro Wilk test indicated normality, $p = 0.568$, $p = 0.0.649$ and $p = 0.568$ for Benepeixcar, Colegiata de Santa Maria and El Raval, respectively: Levene's unequal variance, $p = 0.042$: Kruskal Wallis test demonstrated statistically significant differences in mean $\delta^{15}N$ values, $p = 0.001$). However, as Alexander and colleagues (2015) point out, wide variation in the $\delta^{15}N$ values of archaeological domesticates and fish from the region complicates $\delta^{15}N$ interpretation.

The emphasis on C_4 foods in Valencia reflects the ready adoption of new crops in Spain under Moorish influence (Galloway 2005). Cultivation of sugarcane, which was evident in southern Spain from at least the early 10th century AD, grew in economic importance from 1300-1500 AD. Valencia was one of the most northerly outposts of sugarcane cultivation in Europe, although the crop does not appear to have been cultivated on Ibiza (cf. Galloway 2005).

Elsewhere in the western Mediterranean region there is similar variation in stable isotope signatures, and by inference, diet. At early to middle mediaeval sites in Fruili-Venezia, Guilia, in northeastern Italy, considerable variation in diet is evident with C_4 cereals comprising from 0% up to 29% of dietary protein (Iacumin et al. 2014). The consumption of millets was attributed by Iacumin et al. (2014) to the economic and social upheaval following the demise of the Roman Empire along with climatic deterioration resulting in reduced wheat production and reduced access to higher quality cereals among lower status individuals. By contrast, at Trino Vercellese in northwestern Italy, a necropolis which was in use between the 8th and the 12th centuries AD, diet was dominated by terrestrial C_3 resources with potentially a small proportion of C_4 cereals. In the eastern Mediterranean there is little evidence in isotope signatures for the use of C_4 resources in the Byzantine period: diets were dominated by C_3 resources with varying proportions of marine foods constituting an important but secondary source of protein (Bourbou et al. 2011).

The consumption of small quantities of fish is often cited as a possible explanation for the wide spread of $\delta^{15}N$ values among mediaeval populations (e.g. Mundee 2009; Reitsema and Vercellotti 2012; Quirós Castillo 2013; Iacumin et al. 2014; Alexander et al. 2015). Although faith-based differences in the consumption of marine resources might be anticipated there is little evidence to support this view. Fish did not contribute significantly to population level diet in the western Mediterranean despite the widely held view that fish would have been consumed by Christians on fast days. This may relate to the high cost of fish and the limited impact of meat abstinence on other than the highest status households (Dyer 1983; Adamson 2004). On Ibiza, from Punic times and throughout the Roman and Early Byzantine periods, there is a little to no input of marine resources evident in diet (e.g. Fuller et al. 2010; Salazar-García 2011): this neglect of the sea foods continued into the medieval period.

Consumption of fish with scales is permissible under Islamic dietary law (Regenstein et al. 2003) and fish may have been important to the Islamic population at Tauste, Zaragoza, which is located in the interior of north-east Spain on the banks of the River Arba. Adult $\delta^{13}C$ values range from –19.5‰ to –18.4‰ and $\delta^{15}N$ values from 9.5‰ to 17.0‰ (Guede et al. 2015). Guede et al. (2015) interpreted these values as indicative of a terrestrial C_3 diet, explaining the unusually elevated $\delta^{15}N$ values as the result of aridity and/or salinity rather than the consumption of marine resources owing to the inland location of the site. However, ^{15}N enrichment is not evident in the contemporary population from the nearby site at Zaragoza (Mundee 2009; Quirós Castillo 2013). An alternative interpretation for $\delta^{13}C$ values in the terrestrial C_3 range along with very elevated $\delta^{15}N$ values is the consumption of freshwater fish (e.g. Bonsall et al. 1997; Fuller et al. 2012b), and an indicator of high status in mediaeval Spain (García-Sánchez 2002).

Previous studies have identified sex-based differences in isotope values in mediaeval populations that indicate differential access to resources (e.g. Reitsema and Vercellotti 2012; Quirós Castillo 2013). Quirós Castillo (2013) argued that food was used as one expression of the inequality of men and women in mediaeval Spain. However, this discrimination is not universally manifest and is not evident at Can Fonoll nor at Colegiata de Santa Maria (Alexander et al. 2015).

Diets of later mediaeval groups at Gandía (Benipeixcar *versus* Colegiata de Santa Maria) are distinctive and, potentially, reflect religious practices (Alexander et al. 2015). Religious affiliation was communicated through differences in diet, although Constable (2013) argued that prior to the later mediaeval period the foodways of Christian, Jews and Muslims in Spain were largely shared. On a wider geographic scale (i.e. above the level of individual communities) differences in diet in Spain and elsewhere in the western Mediterranean in the mediaeval period appear to be largely related to regional socioeconomic and environmental considerations. It could be argued that this supports Constable's (2013) assertion that in the earlier mediaeval period foodways were shared across faiths. However, identification of faith-based differences in diet may be obscured by the relatively small number and restricted geographic range of populations that have been analysed to date. Another confounding factor is the difficulty of identifying faith from burial practice (e.g. Rutgers 1992). Further research into the dietary patterns of different faith groups are warranted both on mainland Spain and in particular on Ibiza (where Islamic populations have been the focus of published studies) to investigate the extent and cause(s) of dietary variability in mediaeval populations.

CONCLUSION

The data presented add to our understanding of variation in diet in mediaeval Spain. Stable carbon and nitrogen isotope ratio analysis of the Islamic population interred at Can Fonoll on the island of Ibiza indicates, for most individuals, a diet based on C_3 terrestrial resources, with meat or dairy produce likely important, reflecting the agricultural economy of this community. The wide range of stable isotope values points to differences in individual diet: a small number of those interred at Can Fonoll consumed a significant proportion of C_4 resources in addition to C_3 foods, while one individual has a carbon isotope value suggesting dependence on C_4 resources. These individuals likely migrated to Ibiza from areas with distinct resources, and one possible place of origin is Africa. Similarly, differences in individual diet at other sites on Ibiza and on mainland Spain, for example at Es Soto and Jaca, may also attest to residential mobility, although differential access to resources relating to sex, status and labour cannot be entirely discounted.

Further exploration of diet in mediaeval populations is required to fully appreciate the regional variability of diet and to assess the effects of the religious, social and economic changes brought in the first instance by the Moorish conquest in the 8th century AD to the complete control of Christians in Spain by the 15th century.

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REFERENCES

Adamson MW (2004) Food in Medieval Times. Westport, Connecticut, Greenwood Press

Alexander MM, Gerrard CM, Gutiérrez A, Millard AR. (2015) Diet, society, and economy in late medieval Spain: Stable isotope evidence from Muslims and Christians from Gandía, Valencia. Am J Phys Anthropol 156:263–273. doi:10.1002/ajpa.22647

Alonso N, Antolín F, Kirchner H (2014) Novelties and legacies in crops of the Islamic period in the northeast Iberian Peninsula: The archaeobotanical evidence in Madîna Balagî, Madîna Lârida, and Madîna Turṭûša. Quat Int 346: 149–161. doi:10.1016/j.quaint.2014.04.026

Alonso Martinez N (2005) Agriculture and food from the Roman to the Islamic Period in the North-East of the Iberian peninsula: archaeobotanical studies in the city of Lleida (Catalonia, Spain). Veget Hist Archaeobot 14: 341–361. doi:10.1007/s00334-005-0089-4

Ambrose SH, DeNiro MJ (1986) Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios. Nature 319: 321–324. doi:10.1038/319321a0

Ambrose SH, Norr L (1993) Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert JB, Grupe G, editors. Prehistoric Human Bone: Archaeology at the Molecular Level. Berlin: Springer Verlag, pp. 1–37

An C, Dong W, Li H, Zhang P, Zhao Y, Zhao X, Yu Sh. 2015. Variability of stable carbon isotope ratio in modern and archaeological millets: evidence from northern China. J Archaeol Sci 53:316–322. doi:10.1016/j.jas.2014.11.001

Araus JL, Febrero A, Buxo R, Camalich, MD, Martin D, Molina F, Rodriguez-Ariza MO, Romagosa I (1997) Changes in carbon isotope discrimination in grain cereals from different regions of the western Mediterranean Basin during the past seven millennia. Palaeoenvironmental evidence of a differential change in aridity during the late Holocene. Global Change Biology 3:107–118. doi:10.1046/j.1365-2486.1997.00056.x

Badalamenti F, D'Anna G, Pinnegar J, Polunin N (2002) Size-related trophodynamic changes in three target fish species recovering from intensive trawling. Mar Biol 141:561–570. doi:10.1007/s00227-002-0844-3

Bocherens H, Drucker D (2003) Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. Int J Osteoarchaeol 13:46–53. doi:10.1002/oa.662

Bogaard A, Fraser R, Heaton THE, Wallace M, Vaiglova P, Charles M, Jones G, Evershed RP, Styring AK, Andersen NH, Arbogast R-M, Bartosiewicz L, Gardeisen A, Kanstrup M, Maier U, Marinova E, Ninov L, Schäfer M, Stephan E (2013) Crop manuring and intensive land management by Europe’s first farmers. Proc Natl Acad Sci USA 110:12589–12594. doi:10.1073/pnas.1305918110

Bolens L (1978) La Révolution agricole andalouse du XIe siècle. Studia Islamica 47: 121–141.

Bonsall C, Cook GT, Hedges REM, Higham TFG, Pickard C, Radovanovic I (2004) Radiocarbon and stable isotope evidence of dietary change from the Mesolithic to the middle ages in the Iron Gates: new results from Lepenski Vir. Radiocarbon 46:293–300. doi:10.2458/azu_js_rc.46.4269

Bonsall C, Lennon R, McSweeney K, Stewart C, Harkness D, Boroneanţ (1997) Mesolithic and Early Neolithic in the Iron Gates: a palaeodietary perspective. J Eur Archaeol 5:50–92. doi:10.1179/096576697800703575

Bourbou C, Fuller BT, Garvie-Lok SJ, Richards MP (2011) Reconstructing the diets of Greek Byzantine populations (6th–15th centuries AD) using carbon and nitrogen stable isotope ratios. Am J Phys Anthropol 146:569–581. doi:10.1002/ajpa.21601

Brickley M, Mckinley JI, eds (2004) Guidelines to the Standards for Recording Human Remains. Institute of Field Archaeologists Paper 7. Southampton and Reading, British Association for Biological Anthropology and Osteoarchaeology and Institute of Field Archaeologists

Brown TA, Nelson DE, Vogel JS, Southon JR (1988) Improved collagen extraction by modified Longin method. Radiocarbon 30:171–177. doi:10.2458/azu_js_rc.30.1096

Buikstra JE, Ubelaker DH, eds (1994) Standards for Data Collection from Human Skeletal Remains. Fayetteville, Arkansas, Arkansas Archaeological Survey Research Series No. 44

Burns RI (2015) Islam under the crusaders: colonial survival in the thirteenth-century kingdom of Valencia. Princeton, Princeton University Press

Castro OJ (2009) La intervenció arqueològica al sector IV de la necropolis medieval islàmica de Can Fonoll, durant el seguiment arqueològic del nou accés a l'aeroport d'Evissa. Quaderns d'Arqueologia Ebusitana I:112–119

Chisholm BS, Nelson E, Schwarcz HP (1982) Stable-Carbon Isotope Ratios as a Measure of Marine Versus Terrestrial Protein in Ancient Diets. Science 216:1131–1132. doi:10.1126/science.216.4550.1131

Commendador AS, Dudgeon JV, Finney BP, Fuller BT, Esh KS (2013) Stable isotope ($\delta^{13}C$ and $\delta^{15}N$) perspective on human diet on Rapa Nui (Easter Island) c.a. 1400-1900 AD. Am J Phys Anthropol 152:173–185. doi:10.1002/ajpa.22339

Constable OR (2013) Food and Meaning: Christian understandings of Muslim food and food ways in Spain, 1250-1550. Viator 44:199–236. doi:10.1484/J.VIATOR.1.103484

Craig OE, Biazzo M, O'Connell TC, Garnsey P, Martinez-Labarga C, Lelli R, Salvadei L, Tartaglia G, Nava A, Renò L, Fiammenghi A, Rickards O, Bondioli L (2009) Stable Isotopic Evidence for Diet at the Imperial Roman Coastal Site of Velia (1st and 2nd Centuries AD) in Southern Italy. Am J Phys Anthropol 139: 572–583. doi: 10.1002/ajpa.21021

Craig OE, Bondioli L, Fattore L, Higham T, Hedges R (2013) Evaluating marine diets through radiocarbon dating and stable isotope analysis of victims of the AD79 eruption of Vesuvius. Am J Phys Anthropol 152:345–352. doi:10.1002/ajpa.22352

Davies PR (2014) Ibiza and Formentera's Heritage: A Non-Clubber's Guide. Ibiza, Barbary Press

Dembińska M (1999) Food and Drink in Medieval Poland. Rediscovering a cuisine of the past. (Translated by M. Thomas. Revised and adapted by William Woys Weaver). Philadelphia, University of Pennsylvania Press

DeNiro MJ (1985) Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317:806–809. doi:10.1038/317806a0

DeNiro MJ, Epstein S (1978) Influence of diet on the distribution of carbon isotopes in animals. Geochim Cosmochim Ac 42:495–506. doi:10.1016/0016-7037(78)90199-0

DeNiro MJ, Schoeninger MJ (1983) Stable carbon and nitrogen isotope ratios of bone collagen: variations within individuals, between sexes, and within populations raised on monotonous diets. J Archaeol Sci 10:199–203. doi:10.1016/0305-4403(83)90002-X

Dyer CM (1983) English diet in the later Middle Ages. In: Aston TH, Cross PR, Dyer C, Thirsk J (eds) Social relations and ideas: essays in honour of RH Hilton. Cambridge, Cambridge University Press, pp. 191–216

Fraser R, Bogaard A, Heaton T, Charles M, Jones G, Christensen BT, Halstead P, Merbach I, Poulton PR, Sparkes D, Styring AK (2011) Manure and stable isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices. J Archaeol Sci 38:2790–2804. doi:10.1016/j.jas.2011.06.024

Fuller BT, Fuller JL, Sage NE, Harris DA, O'Connell TC, Hedges REM (2005) Nitrogen balance and $\delta^{15}N$: why you're not what you eat during nutritional stress. Rapid Commun Mass Sp 19:2497–2506. doi:10.1002/rcm.2090

Fuller BT, Márquez-Grant N, Richards MP (2010) Investigation of Diachronic Dietary Patterns on the Islands of Ibiza and Formentera, Spain: Evidence from Carbon and Nitrogen Stable Isotope Ratio Analysis. Am J Phys Anthropol 143:512–522. doi:10.1002/ajpa.21334

Fuller BT, De Cupere B, Marinova E, van Neer W, Waelkens M, Richards MP (2012a) Isotopic reconstruction of human diet and animal husbandry practices during the Classical-Hellenistic, Imperial and Byzantine Periods at Sagalassos, Turkey. Am J Phys Anthropol 149:157–171. doi:10.1002/ajpa.22100

Fuller BT, Müldner G, Van Neer W, Ervynck A, Richards MP (2012b) Carbon and nitrogen stable isotope ratio analysis of freshwater, brackish and marine fish from Belgian archaeological sites (1st and 2nd millennium AD). J Anal Atom Spectrom 27:807–820. doi:10.1039/C2JA10366D

Galloway JH (2005) The Sugar Cane Industry: An Historical Geography from its Origins to 1914. Cambridge Studies in Historical Geography. Cambridge, Cambridge University Press

García-Sánchez E (1996) La alimentación popular urbana en al-Andalus. Arqueología medieval 4:219–36

García-Sánchez E (2002) Dietetic aspects of food in Al-Andalus. In: Waines D (ed) Patterns of Everyday Life. Hampshire, Ashgate, pp. 275–288

Garnero P, Sornay-Rendu E, Chapuy M-C, Delmas PD (1996) Increased bone turnover in late postmenopausal women is a major determinant of osteoporosis. J Bone Miner Res 11:337–349. doi:10.1002/jbmr.5650110307

Garvie-Lok S (2001) Loaves and fishes: a stable isotope reconstruction of diet in Medieval Greece. PhD Dissertation, University of Calgary, Calgary

Grewe R (1981) Catalan Cuisine, in an Historical Perspective. In: Davidson A (ed.) National and Regional Styles of Cookery. Oxford Symposium 1981 Proceedings. Oxford, Oxford University Press, pp. 170–178

Guede I, Ortega LA, Zuluaga MC, Alonso A, Muerlaga X, Pina M, Gutiérrez FJ (2015) δ^{13}C, δ^{15}N y paleodieta en restos humanos de la necropolis islámica medieval de Tauste (Zaragoza). Revista de la Sociedad Española de Mineralogía 20:69–70

Gurrea Barricarte R, Martín Parrilla Á (2016) Eivissa-Història-Època andalusina. L'Enciclopèdia d'Eivissa i Formentera. Consell d'Eivissa. www.eeif.es

Hedges REM (2004) Isotopes and red herrings: comments on Milner et al. and Lidén et al. Antiquity 78:34–37. doi:10.1017/S0003598X00092905

Hedges REM, Clement JG, Thomas CD, O'Connell TC (2007) Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. Am J Phys Anthropol 133:808–816. doi:10.1002/ajpa.20598

Hedges REM, Reynard LM (2007) Nitrogen isotopes and the trophic level of humans in archaeology. J Archaeol Sci 34:1240–1251. doi:10.1016/j.jas.2006.10.015

Iacumin P, Galli E, Cavalli F, Cecere L. 2014. C4-Consumers in Southern Europe: The Case of Friuli V.G. (NE-Italy) During Early and Central Middle Ages. Am J Phys Anthropol 154: 561–574. doi:10.1002/ajpa.22553

Katzenberg MA (2000) Stable isotope analysis: a tool for studying past diet, demography and life history. In: Katzenberg MA, Saunders SA (eds) Biological Anthropology of the Human Skeleton. New York, Wiley-Liss, pp. 305–328

Keenleyside A, Schwarcz H, Panayotova K (2006) Stable isotopic evidence of diet in a Greek colonial population from the Black Sea. J Archaeol Sci 33:1205–1215. doi:10.1016/j.jas.2005.12.008

Kirchner H (2009a) Original design, tribal management and modifications in medieval hydraulic systems in the Balearic Islands (Spain). World Archaeol 41: 151-168. doi:10.1080/00438240802668222

Kirchner H (2009b) Watermills in the Balearic Islands during the Muslim period. In: Klápště J, Sommer P (eds) Processing, Storage, Distribution of Food. Food in the Medieval Rural Environment. Ruralia VIII, 7th-12th September 2009, Lorca, Spain. Turnhout, Belgium, Brepols Pub, pp. 45–55

Krueger HW, Sullivan CH (1984) Models for carbon isotope fractionation between diet and bone. In: Turnlund JE, Johnson PE (eds) Stable Isotopes in Nutrition American Chemical Society Symposium Series 258. Washington DC, American Chemical Society, pp. 205–222

Kyriakou XP, Márquez-Grant N, Langstaff H, Fleming-Farrell D, Samuels C, Harris S, Pacelli CS, Migliaccio F, Castro J, Roig J, Kranioti EF (2012) The Human Remains from the Mediaeval Islamic Cemetery of Can Fonoll, Ibiza, Spain. In: Mitchell P, Buckberry J (eds) Proceedings of the 12th Annual Conference for BABAO. Oxford, BAR International series 2380, pp. 87–101

Lalueza-Fox C, González Martín A (1999) Oral pathology in the Iberian Peninsula and Balearic Islands from the Mesolithic to present times. Homo 49:260–272

Le Huray JD, Schutkowski H (2005) Diet and social status during the La Tène period in Bohemia: Carbon and nitrogen stable isotope analysis of bone collagen from Kutná Hora-Karlov and Radovesice. J Anthropol Archaeol 24:135–147. doi:10.1016/j.jaa.2004.09.002

Lee-Thorp JA (2008) On isotopes and old bones. Archaeometry 50: 925–950. doi:10.1111/j.1475-4754.2008.00441.x

Lightfoot E, Liu X, Jones MK (2013) Why move starchy cereals? A review of the isotopic evidence for prehistoric millet consumption across Eurasia. World Archaeol 45:574–623. doi:10.1080/00438243.2013.852070

Loftus E, Roberts P, Lee-Thorp JA (2016) An isotopic generation: four decades of stable isotope analysis in African archaeology. Azania: Archaeological Research in Africa 51:88–114. doi:10.1080/0067270X.2016.1150083

Lubritto C, Sirignano C, Ricci P, Passariello I, Quirós Castillo JA (2013) Radiocarbon chronology and paleo-diet studies on the medieval site of Zaballa (Spain): preliminary insights into the social archaeology of the site. Radiocarbon 55:1222–1232. doi:10.2458/azu_js_rc.55.16365

Manolagas SC, Jilka RL (1995) Bone marrow, cytokines and bone remodeling. N Engl J Med 332:305–11. doi:10.1056/NEJM199502023320506

Márquez-Grant N (2005) The Presence of African Individuals in Punic Populations from the Island of Ibiza (Spain): Contributions from Physical Anthropology. Mayurqa 30: 611–637

Márquez-Grant N (2006) A bioanthropological perspective of the Punic period in Ibiza (Spain) as evidenced by human skeletal remains. Unpublished DPhil thesis, University of Oxford

McGovern PE, Zhang JH, Tang JG, Zhang ZQ, Hall GR, Moreau RA, Nunez A, Butrym ED, Richards MP, Wang CS, Cheng GS, Zhao ZJ, Wang CS (2004) Fermented beverages of pre- and proto-historic China. P Natl Acad Sci USA 101:17593–17598. doi:10.1073/pnas.0407921102

McMillan PG, Boone LJ (1999) Population History and the Islamization of the Iberian Peninsula: Skeletal Evidence from the Lower Alentejo of Portugal. Curr Anthropol 40:719–726

Motuzaite-Matuzeviciute G, Staff RA, Hunt HV, Liu X, Jones MK (2013) The early chronology of broomcorn millet (*Panicum miliaceum*) in Europe. Antiquity 338:1073–1085. doi:10.1017/S0003598X00049875

Müldner G, Chenery C, Eckhardt H (2011) The 'Headless Romans': multi-isotope investigations of an unusual burial ground from Roman Britain. J Archaeol Sci 38:280–290. doi:10.1016/j.jas.2010.09.003

Müldner G, Richards MP (2007) Stable isotope evidence for 1500 years of human diet in the city of York, UK. Am J Phys Anthropol 133:682–697. doi:10.1002/ajpa.20561

Mundee M (2009) An isotopic approach to diet in Medieval Spain. In Baker S, Allen M, Middle S, Poole K (eds) Food and Drink in Archaeology 2. Nottingham, Prospect Books, pp. 64–72

Murphy K (2011) A Meal on the Hoof or Wealth in the Kraal? Stable Isotoptes at Kgaswe and Taukome in Eastern Botswana. Int J Osteoarchaeol 21:591–601. doi:10.1002/oa.1166

Murray M, Schoeninger MJ (1988) Diet, Status, and Complex Social Structure in Iron Age Central Europe: Some Contributions of Bone Chemistry. In: Gibson DB, Geselowitz M (eds) Tribe and Polity in Late Prehistoric Europe. New York, Plenum, pp. 155–176

Naylor KE, Iqbal P, Fledelius C, Fraser RB, Eastell R (2000) The effect of pregnancy on bone density and bone turnover. J Bone Miner Res 15:129–137. doi:10.1359/jbmr.2000.15.1.129

Nehlich O, Fuller BT, Márquez-Grant N, Richards MP (2012) Investigation of Diachronic Dietary Patterns on the Islands of Ibiza and Formentera, Spain: Evidence from Sulfur Stable Isotope Ratio Analysis. Am J Phys Anthropol 149:115–124. doi:10.1002/ajpa.22104

O'Connell TC, Kneale CJ, Tasevska N, Kuhnle GGC (2012) The diet-body offset in human nitrogen isotopic values: A controlled dietary study. Am J Phys Anthropol 149:426–443. doi:10.1002/ajpa.22140

O'Connor IA (2003) A Forgotten Community: The Mudejar Aljama of Xátiva. 1240-1327. Boston, Brill

Olsen KC, White CD, Longstaffe FJ, von Heyking K, McGlynn G, Grupe G, Rühli FJ (2014) Intraskeletal isotopic compositions ($\delta^{13}C$, $\delta^{15}N$) of bone collagen: nonpathological and pathological variation. Am J Phys Anthropol 53:598–604. doi:10.1002/ajpa.22459

Pate FM, Alvarez J, Phillips JD, Eiland BR (2002) Sugar cane as a Cattle Feed: Production and Utilization. Bulletin No. 844. Gainsville, Department of Animal Sciences, Institute of Food and Agricultural Sciences, University of Florida

Pechenkina EA, Ambrose SH, Ma X, Benfer RA Jr (2005) Reconstructing northern Chinese Neolithic subsistence practices by isotopic analysis. J Archaeol Sci 32:1176–1189. doi:10.1016/j.jas.2005.02.015

Pinnegar JK, and Polunin NVC (2000) Contributions of stable-isotope data to elucidating food webs of Mediterranean rocky littoral fishes. Oecologia 122:399–409. doi:10.1007/s004420050046

Polunin NVC, Morales-Nin B, Pawsey WE, Cartes JE, Pinnegar JK, Moranta J (2001) Feeding relationships in Mediterranean bathyal assemblages elucidated by stable nitrogen and carbon isotope data. Mar Ecol-Prog Ser 220:13–23. doi:10.3354/meps220013

Puy A, Balbo AL (2013) The genesis of irrigated terraces in al-Andalus. A geoarchaeological perspective on intensive agriculture in semi-arid environments (Ricote, Murcia, Spain). J Arid Environ 89: 45–56. doi:10.1016/j.jaridenv.2012.10.008

Prowse T, Schwarcz HP, Saunders S, Macchiarelli R, Bondioli L (2004) Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. J Archaeol Sci 31:259–272. doi:10.1016/j.jas.2003.08.008

Quintelier K, Ervynck A, Müldner G, Van Neer W, Richards MP, Fuller BT (2014) Isotopic Examination of Links Between Diet, Social Differentiation, and DISH at the Post-Medieval Carmelite Friary of Aalst, Belgium. Am J Phys Anthropol 153:203–213. doi:10.1002/ajpa.22420

Quirós Castillo JA (2013) Los comportamientos alimentarios del campesinado medieval en el País Vasco y su entorno (siglos VIII–XIV). Historia Agraria 59:13–41

Rees CE, Jenkins WJ, Monster J (1978) The sulphur isotopic composition of ocean water sulphate. Geochim Cosmochim Ac 42:377–381. doi:10.1016/0016-7037(78)90268-5

Reitsema LJ (2013) Beyond diet reconstruction: Stable isotope applications to human physiology, health, and nutrition. Am J Hum Biol 25:445–456. doi:10.1002/ajhb.22398

Reitsema LJ, Vercellotti G (2013) Stable isotope evidence for sex- and status-based variations in diet and life history at medieval Trino Vercellese, Italy. Am J Phys Anthropol 148: 589–600. doi:10.1002/ajpa.22085

Richards MP, Hedges REM (1999) Stable isotope evidence for similarities in the types of marine foods used by late Mesolithic humans at sites along the Atlantic coast of Europe. J Archaeol Sci 26:717–722. doi:10.1006/jasc.1998.0387

Richards MP, Fuller BT, Hedges REM (2001) Sulphur isotopic variation in ancient bone collagen from Europe: implications for human palaeodiet, residence mobility, and modern pollutant studies. Earth Planet Sci Lett 191:185–190. doi:10.1016/S0012-821X(01)00427-7

Richards MP, Taylor G, Steele T, McPherron SP, Soressi M, Jaubert J, Orschiedt J, Mallye JB, Rendu W, Hublin JJ (2008) Isotopic dietary analysis of a Neanderthal and associated fauna from the site of Jonzac (Charente-Maritime), France. J Hum Evol 55:179–185. doi:10.1016/j.jhevol.2008.02.007

Rösch M, Jacomet S, Karg S (1992) The history of cereals in the region of the former Duchy of Swabia (Herzogtum Schwaben) from the Roman to the Post-medieval period: results of archaeobotanical research. Veg Hist Archaeobot 1:193–231. doi:10.1007/BF00189499

Rutgers LV (1992) Archaeological Evidence for the Interaction of Jews and Non-Jews in Late Antiquity. Am J Archaeol 96:101–108. doi:10.2307/505760.

Salazar-García DC (2011) Patrón de dieta en la población púnica de Can Marines (Ibiza) a través del análisis de isótopos estables (C y N) en colágeno óseo. SAGVNTVM (P.L.A.V.) 43:95–102. doi:10.7203/SAGVNTVM.43.1213

Salazar-García DC, Richards MP, Nehlich O, Henry AG (2014) Dental calculus is not equivalent to bone collagen for isotope analysis: a comparison between carbon and nitrogen stable isotope analysis of bulk dental calculus, bone and dentine collagen from same individuals from the Medieval site of El Raval (Alicante, Spain). J Archaeol Sci 47:70–77. doi:10.1016/j.jas.2014.03.026

Schoeninger MJ (2010) Diet reconstruction and ecology using stable isotope ratios. In: Larsen CS (ed) A companion to biological anthropology. Chichester, Wiley-Blackwell, pp. 445–464

Schoeninger MJ, DeNiro MJ (1984) Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochim Cosmochim Ac 48:625–639. doi:10.1016/0016-7037(84)90091-7

Schoeninger MJ, van der Merwe NJ, Moore K, Lee Thorp J, Larsen (1990) Decrease in diet quality between the Prehistoric and the Contact periods. In: Larsen CS (ed.) The Archaeology of Mission Santa Catalina De Guale: 2. New York, American Museum of Natural History, pp. 78–93

Schwarcz HP, Schoeninger MJ (2011) Stable Isotopes of Carbon and Nitrogen as Tracers for Paleo-Diet Reconstruction. In: Baskaran M (ed) Handbook of Environmental Isotope Geochemistry. Berlin/Heidelberg, Springer-Verlag, pp. 725–742

Sealy JC, van der Merwe NJ, Lee-Thorp JA, Lanham JL (1987) Nitrogen isotope ecology in southern Africa: Implications for environmental and dietary tracing. Geochim Cosmochim Ac

51:2707–2717. doi:10.1016/0016-7037(87)90151-7

Sealy J (2001) Body tissue chemistry and paleodiet. In: Brothwell DR, Pollard AM (eds) Handbook of Archaeological Sciences. Chichester, Wiley, pp. 269–279

Szpak P, Longstaffe FJ, Millaire J-F, White CD (2014) Large variation in nitrogen isotopic composition of a fertilized legume. J Archaeol Sci 45:72–79. doi: 10.1016/j.jas.2014.02.007

Tafuri MA, Craig OE, Canci A (2009) Stable Isotope Evidence for the Consumption of Millet and Other Plants in Bronze Age Italy. Am J Phys Anthropol 139:146–153. doi:10.1002/ajpa.20955

Thorsen K, Kristoffersson A, Hultdin J, Lorentzon R (1997) Effects of moderate endurance exercise on calcium, parathyroid hormone and markers of bone metabolism in young women. Calcif Tissue Int 60:16-20. doi:10.1007/s002239900179

Tsutaya T, Yoneda M (2013) Quantitative reconstruction of weaning ages in archaeological human populations using bone collagen nitrogen isotope ratios and approximate Bayesian computation. PLoS ONE 8(8): e72327. doi:10.1371/journal.pone.0072327

Tykot RH (2004) Stable isotopes and diet: You are what you eat. In: Martini M, Milazzo M, Piacentini M (eds) Physics Methods in Archaeometry. Proceedings of the International School of Physics “Enrico Fermi” Course CLIV. Amsterdam, IOS Press, pp. 433–444

van der Merwe NJ, Vogel JC (1978) ^{13}C content of human collagen as a measure of prehistoric diet in Woodland North America. Nature 276:815–816. doi:10.1038/276815a0

van Klinken GJ (1999) Bone collagen quality indicator for palaeodietary and radiocarbon measurements. J Archaeol Sci 26:687–695. doi:10.1006/jasc.1998.0385

Watson AM (1983) Agricultural Innovation in the Early Islamic World: The Diffusion of Crops and Farming Techniques, 700-1100. Cambridge Studies in Islamic Civilization. Cambridge, Cambridge University Press.

Figure 1. Location of Can Fonoll, Ibiza, Spain.

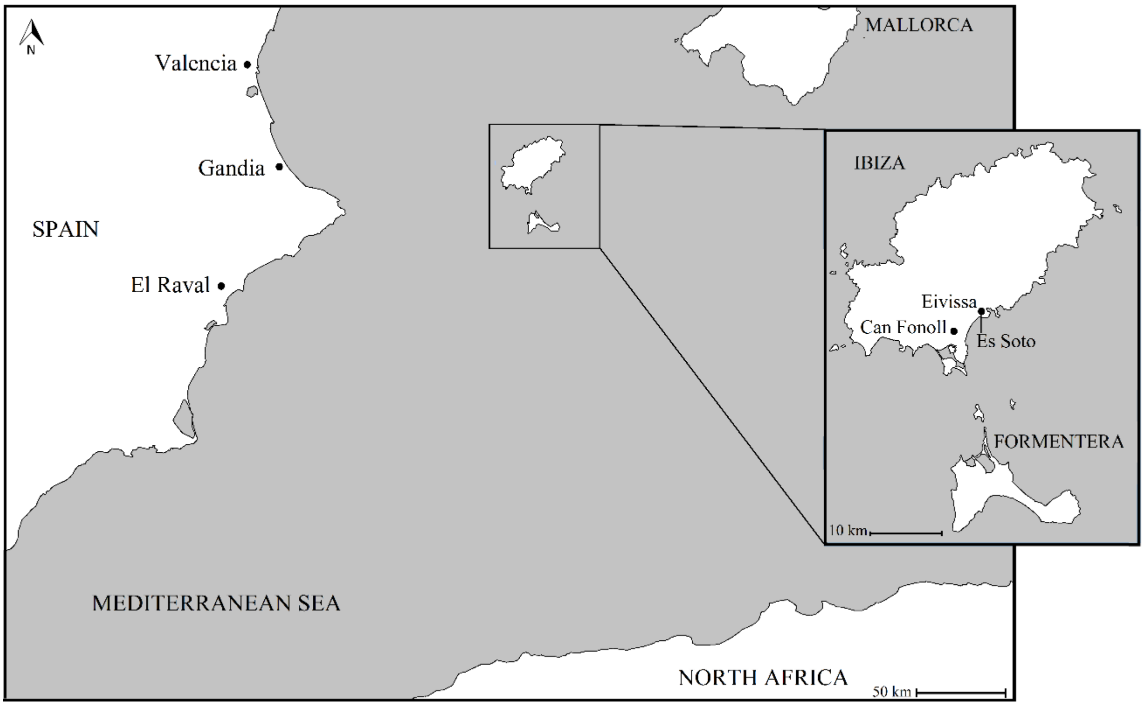

Figure 2. Photograph of excavated graves at Can Fonoll necropolis (© Jonathan Castro Orellana and Joan Roig).

Figure 3. Scatterplot of mean±sd(1σ) $\delta^{13}C$ and $\delta^{15}N$ values for the Can Fonoll humans.

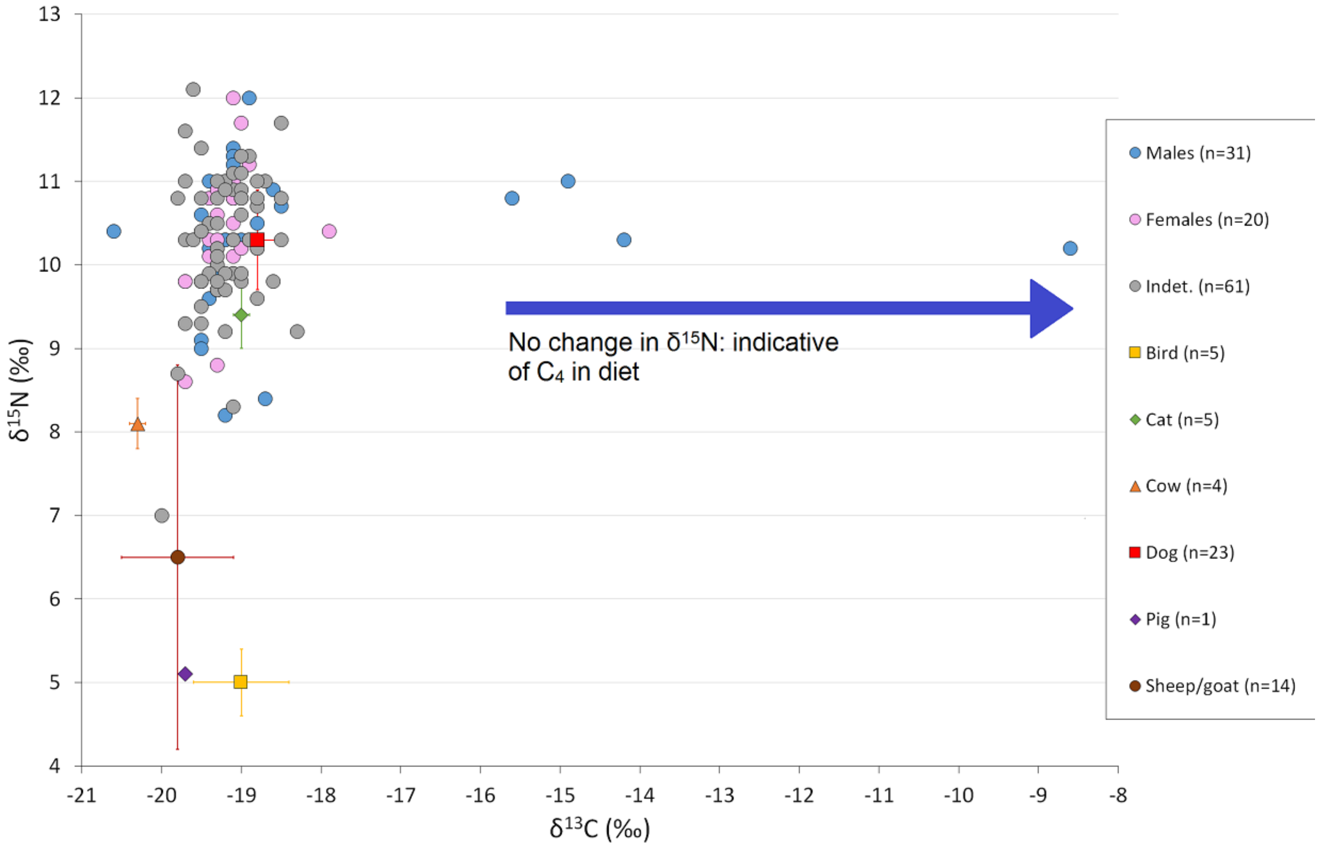

Figure 4. Scatterplot of stable isotope values of key Ibizan and Valencian Spanish mediaeval sites discussed.

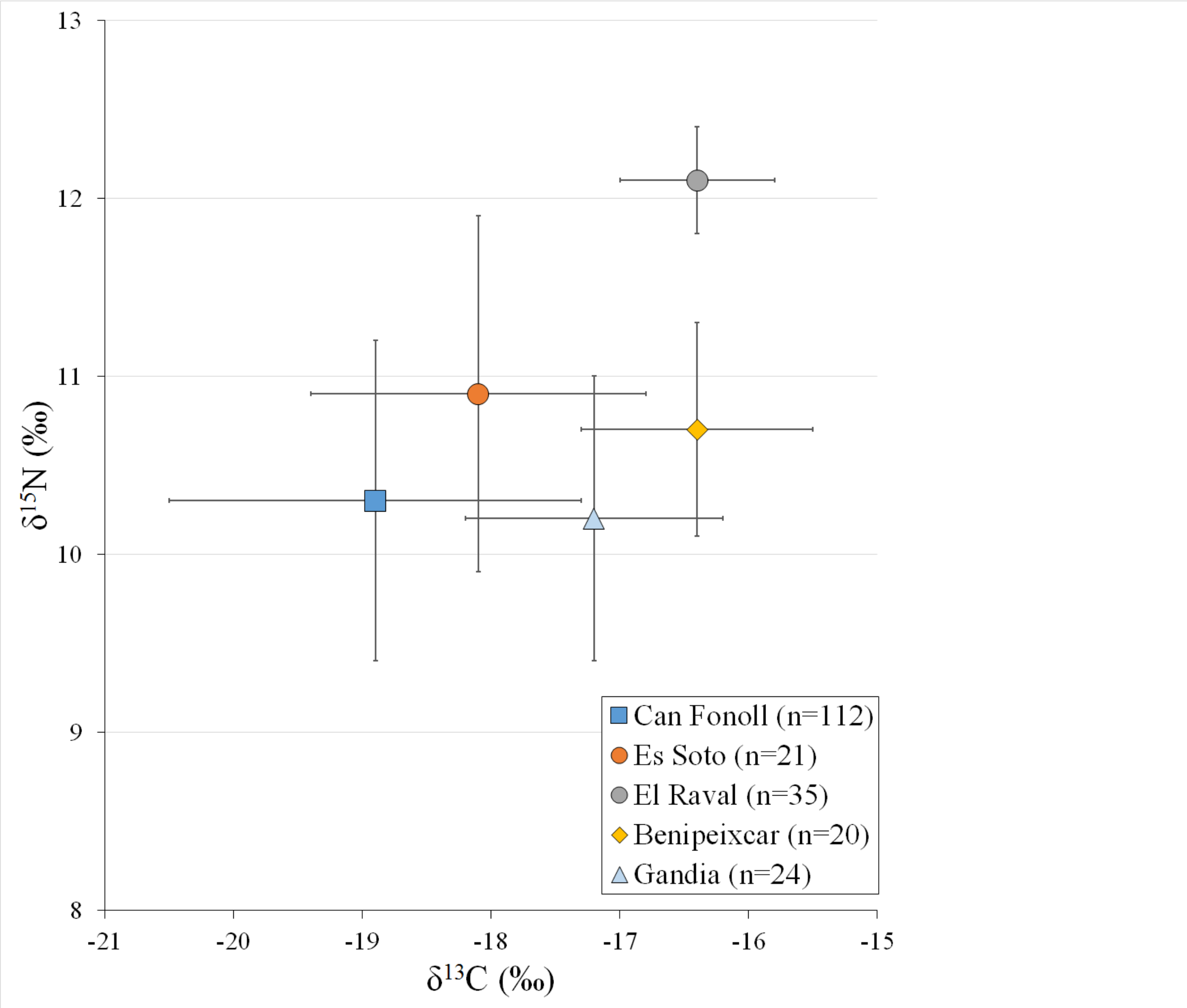

Table 1. Mean±sd(1σ) $\delta^{13}C$ and $\delta^{15}N$ values of animal remains from Ibiza, taken from Fuller et al. (2010).

Species	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**	**n**
Cat	-19.0±0.1	9.4±0.4	7
Bird	-19.0±0.6	8.0±0.4	5
Dog	-18.8±0.3	10.3±0.6	23
Cow	-20.3±0.1	8.1±0.3	4
Sheep/goat	-19.8±0.7	6.5±2.3	14
Pig	-19.7	5.1	1

Table 2. Mean±sd(1σ) bone collagen $\delta^{13}C$ and $\delta^{15}N$ values of human remains from Ibiza and mediaeval populations from the Mediterranean region.

Site	Period	Affiliation	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	n	Reference
Ca na Costa, Ibiza	c. 2100 BC	Chalcolithic	-18.9±0.2	12.7±1.7	8	Fuller et al. 2010
Ses Païsses de Cala d'Hort, Ibiza	5^{th}-2^{nd}/1^{st} C BC	Punic (rural)	-18.7±0.3	12.5±0.5	38	Fuller et al. 2010
Puig des Molins, Ibiza	5^{th}-2^{nd}/1^{st} C BC	Punic (urban)	-18.8±0.3	11.3±0.7	8	Fuller et al. 2010
S'Hort des Llimoners, Ibiza	4^{th}-6^{th} C AD	Late Antiquity-Early Byzantine	-19.0±0.4	11.1±1.1	60	Fuller et al. 2010
Can Marines, Ibiza	5^{th}-4^{th} C BC	Punic	-18.5±0.3	11.5±0.4	27	Salazar-García 2011
Es Soto, Ibiza	10^{th}-13^{th} C AD	Mediaeval (Islamic)	-18.1±1.3	10.9±1.0	21	Fuller et al. 2010
Can Fonoll, Ibiza	10^{th}-13^{th} C AD	Mediaeval (Islamic)	-19.0±1.3	10.3±0.8	112	This study
El Raval, Valencia	14^{th}-16^{th} C AD	Mediaeval (Islamic)	-16.4±0.6	12.1±0.3	35	Salazar-García et al. 2014
Gandia (Benipeixcar), Valencia	13^{th}-16^{th} C AD	Mediaeval (Islamic)	-16.4±0.9	10.7±0.6	20	Alexander et al. 2015
Gandia (Colegiata de Santa Maria), Valencia	13^{th}-16^{th} C AD	Mediaeval (Christian)	-17.2±1.0	10.2±0.8	24	Alexander et al. 2015
Tauste, Zaragoza*	8^{th}-12^{th} C AD	Mediaeval (Islamic)	Range -19.9 to -16.9	Range 9.5 to 17.5	30	Guede et al. 2015
Trino Vercellese, Northern Italy	8^{th}-13^{th} C AD	Early-Middle Mediaeval (Christian)	-19.1±0.7	9.2±0.8	28	Reitsema & Vercellotti 2012
Mainizza, Northern Italy	10^{th}-11^{th} C AD	Middle Mediaeval (Christian/pagan?)	-15.9±1.4	7.7±1.0	16	Iacumin et al. 2014
Fruili-Venezia Giulia, Northern Italy	6^{th}-7^{th} C AD	Early Mediaeval	-16.6±0.9	8.4±0.8	66	Iacumin et al. 2014
Saint Tirso, Zaballa, Spain	10^{th}-13^{th} C AD	Middle Mediaeval	-19.8±0.7**	9.0±0.8**	14	Lubritto et al. 2013
Treviño, Spain	12^{th}-15^{th} C AD	Mediaeval	-19.6±0.7	9.6±1.2	15	Quirós Castillo 2013
Zornoztegi, Spain	12^{th}-14^{th} C AD	Mediaeval	-18±1.1	8.3±0.6	7	Quirós Castillo 2013
Aistra, Spain	8^{th}-13^{th} C AD	Mediaeval	-19.0±1.0	7.9±1.1	35	Quirós Castillo 2013

*- full data set was not published by Guede et al. (2015).

**- infants excluded.

Table S1: Supplementary Information

Sample number	Site sector and tomb number	Age	Sex	Collagen yield (%)	$d^{13}C$ (‰)	$d^{15}N$ (‰)	(%)C	(%)N	Atomic C:N
S-EVA-18759	Sector I T-1	25-35	M	0.2	-20.6	10.4	22.7	7.8	3.4
S-EVA-18760	Sector I T-2	18-25	M	0.1	-14.2	10.3	24.9	8.8	3.3
S-EVA-18762	Sector I T-4	?	?	0.1	-19.7	11.6	14.9	5.1	3.4
S-EVA-18763	Sector I T-5	25-35	?	0.6	-19.3	10.8	29.8	10.5	3.3
S-EVA-18764	Sector I T-6	?	?	0.8	-19.5	11.4	23.9	8.3	3.4
S-EVA-18765	Sector I T-7	18-25	F?	0.3	-19.4	10.8	20.4	7.0	3.4
S-EVA-18766	Sector I T-9	25-35	M	0.1	-19.1	10.8	19.9	6.9	3.3
S-EVA-18767	Sector I T-10	25-35	?	0.6	-19.1	10.3	33.9	12.0	3.3
S-EVA-18768	Sector II T-40	18-25	?	0.7	-19.1	10.9	33.1	11.8	3.3
S-EVA-18769	Sector II T-41	18-25	?	0.3	-19.2	11.0	26.5	9.3	3.3
S-EVA-18770	Sector II T-43	18-25	F	0.5	-19.7	9.8	19.1	6.6	3.4
S-EVA-18771	Sector II T-44	18-25	M?	0.7	-19.2	10.3	37.9	13.3	3.3
S-EVA-18775	Sector II T-48	18-25	M	0.9	-19.1	11.4	28.0	9.8	3.3
S-EVA-18776	Sector II T-49	25-35	?	0.5	-18.5	10.8	35.4	12.6	3.3
S-EVA-18779	Sector II T-52	18-25	?	0.6	-19.6	12.1	31.5	11.0	3.3
S-EVA-18781	Sector II T-54	18-25	M	0.2	-19.1	11.3	28.2	9.8	3.4
S-EVA-18782	Sector II T-55	18-25	?	0.2	-19.3	10.0	20.0	6.9	3.4
S-EVA-18786	Sector II T-61	10-15	?	0.2	-19.8	10.8	12.5	4.0	3.6
S-EVA-18787	Sector II T-62	18-25	M?	0.9	-19.4	11.0	25.2	9.4	3.3
S-EVA-18788	Sector II T-63	?	F	0.2	-19.3	10.6	15.0	3.6	3.6
S-EVA-18790	Sector II T-65	18-25	?	0.5	-19.7	10.3	18.5	6.3	3.4
S-EVA-18791	Sector II T-66	18-25	M	1.2	-19.5	10.6	18.2	6.5	3.3
S-EVA-18793	Sector II T-68	25-35	?	0.2	-19.3	11.0	15.3	5.1	3.5
S-EVA-18794	Sector II T-69	18-25	M	2.3	-18.7	8.4	15.7	5.3	3.4
S-EVA-18796	Sector II T-71	18-25	F	0.1	-19.4	10.1	14.6	4.7	3.6
S-EVA-18797	Sector II T-72	?	?	0.6	-19.1	9.9	25.2	9.0	3.3
S-EVA-18799	Sector II T-74	18-25	?	0.4	-18.7	11.0	27.6	10.0	3.2
S-EVA-18800	Sector II T-75	25-35	M	1.8	-18.8	10.5	28.1	10.2	3.2
S-EVA-18801	Sector II T-76	25-35	?	0.6	-18.8	10.2	35.5	13.0	3.2
S-EVA-18802	Sector II T-77	18-25	F	2.4	-18.9	11.2	48.9	19.2	3.0
S-EVA-18803	Sector II T-78	?	?	0.4	-18.9	11.3	29.7	10.5	3.3
S-EVA-18804	Sector III T-11	25-35	F	0.4	-19.3	8.8	14.1	4.8	3.4
S-EVA-18805	Sector III T-12	25-35	M	1.5	-19.2	8.2	16.6	5.6	3.3
S-EVA-18806	Sector III T-13	?	?	2.0	-19.0	11.3	12.4	4.1	3.5
S-EVA-18807	Sector III T-14	25-35	M	0.3	-14.9	11.0	29.6	10.6	3.2
S-EVA-18809	Sector III T-16	18-25	?	0.4	-19.3	10.2	33.3	12.3	3.2
S-EVA-18810	Sector III T-17	18-25	M	0.3	-18.5	10.7	22.6	8.2	3.2
S-EVA-18812	Sector III T-19	?	?	0.2	-19.3	9.7	26.9	9.4	3.3
S-EVA-18813	Sector III T-20	25-35	?	0.6	-18.3	9.2	31.3	11.5	3.2
S-EVA-18814	Sector III T-21	18-25	M	0.7	-19.3	10.9	31.9	12.0	3.1
S-EVA-18816	Sector III T-24	18-25	M	0.3	-19.4	10.2	36.3	13.4	3.2
S-EVA-18817	Sector III T-27	10-15	?	1.5	-19.4	10.5	47.1	18.6	3.0
S-EVA-18818	Sector III T-31	25-35	?	1.8	-19.2	9.2	12.8	4.4	3.4

S-EVA-18819	Sector III T-33	18-25	?	0.7	-19.3	9.7	27.2	9.9	3.2
S-EVA-18820	Sector III T-35	25-35	?	1.5	-19.1	8.3	18.1	6.6	3.2
S-EVA-18821	Sector III T-36	18-25	M	1.1	-19.7	9.8	10.9	3.8	3.4
S-EVA-18823	Sector III T-38	?	M	0.3	-19.1	9.9	26.3	9.5	3.3
S-EVA-18826	Sector IV T-80	35-45	M	0.2	-19.2	10.3	12.6	4.8	3.1
S-EVA-18828	Sector IV T-84	18-25	?	1.4	-18.6	9.8	10.4	3.9	3.2
S-EVA-18829	Sector IV T-86	18-25	M	0.5	-19.5	9.1	14.7	5.5	3.1
S-EVA-18830	Sector IV T-87	?	?	0.3	-18.8	11.0	24.4	8.9	3.2
S-EVA-18831	Sector IV T-88	18-25	M	1.0	-19.5	9.8	27.3	9.9	3.2
S-EVA-18832	Sector IV T-89	18-25	M	1.4	-19.3	9.9	13.8	5.1	3.2
S-EVA-18833	Sector IV T-90	10-15	?	1.3	-19.2	9.9	33.1	12.0	3.2
S-EVA-18835	Sector IV T-92	18-25	?	1.0	-19.1	11.1	35.8	13.0	3.2
S-EVA-18836	Sector IV T-93	25-35	M	3.0	-19.0	10.3	35.9	13.2	3.2
S-EVA-18837	Sector IV T-94	18-25	?	0.8	-18.8	10.7	34.3	12.4	3.2
S-EVA-18838	Sector IV T-95	18-25	F	1.3	-19.5	9.8	11.8	4.2	3.3
S-EVA-18839	Sector IV T-96	18-25	M	0.5	-19.4	9.6	19.6	6.8	3.4
S-EVA-18841	Sector IV T-99	25-35	M	0.3	-15.6	10.8	23.8	8.8	3.2
S-EVA-18842	Sector IV T-101	25-35	?	1.1	-19.4	9.9	12.1	4.5	3.1
S-EVA-18843	Sector IV T-103	18-25	F	2.7	-19.4	10.3	26.5	9.8	3.2
S-EVA-18844	Sector IV T-105	?	?	0.9	-19.7	9.3	11.6	4.3	3.2
S-EVA-18846	Sector IV T-108	18-25	?	0.7	-18.8	9.6	32.1	11.4	3.3
S-EVA-18847	Sector IV T-109	18-25	M	0.6	-19.1	10.3	17.7	6.3	3.3
S-EVA-18848	Sector IV T-100	?	?	0.4	-19.5	9.5	14.1	4.9	3.3
S-EVA-18849	Sector IV T-110	10-15	?	1.1	-19.3	10.2	29.1	10.5	3.2
S-EVA-18850	Sector IV T-111	18-25	?	1.2	-19.3	10.1	12.9	4.6	3.3
S-EVA-18851	Sector IV T-113	18-25	F	0.8	-19.0	11.7	40.2	14.3	3.3
S-EVA-18852	Sector IV T-114	25-35	F	1.6	-19.1	11.0	42.2	15.7	3.1
S-EVA-18853	Sector IV T-115	18-25	?	0.2	-19.5	10.4	10.6	3.4	3.6
S-EVA-18854	Sector IV T-117	18-25	?	1.3	-19.3	9.7	18.3	6.6	3.3
S-EVA-18855	Sector IV T-118	18-25	?	0.2	-19.5	10.8	17.7	6.0	3.4
S-EVA-18856	Sector IV T-119	18-25	F	0.2	-19.7	8.6	7.9	2.8	3.3
S-EVA-18857	Sector IV T-120	18-25	?	2.1	-19.0	9.8	47.2	17.5	3.2
S-EVA-18858	Sector IV T-121	25-35	F	0.3	-17.9	10.4	31.0	11.2	3.2
S-EVA-18859	Sector IV T-122	18-25	?	0.2	-20.0	7.0	3.1	1.2	3.2
S-EVA-18860	Sector IV T-123	1-5	?	0.2	-19.2	9.7	28.3	9.8	3.4
S-EVA-18861	Sector IV T-124	18-25	?	1.4	-18.8	10.2	40.6	15.1	3.1
S-EVA-18862	Sector IV T-125	15-18	?	0.1	-19.6	10.3	23.7	8.0	3.5
S-EVA-18863	Sector IV T-126	25-35	M	0.6	-18.9	12.0	8.8	3.1	3.3
S-EVA-18864	Sector IV T-127	18-25	F	0.4	-19.1	10.5	30.6	10.5	3.4
S-EVA-18865	Sector IV T-128	15-18	F	1.1	-19.3	9.8	39.0	14.2	3.2
S-EVA-18866	Sector IV T-129	18-25	F	0.3	-19.1	10.8	32.7	11.3	3.4
S-EVA-18867	Sector IV T-130	18-25	F?	0.1	-19.1	12.0	11.7	4.1	3.3
S-EVA-18868	Sector IV T-131	5-10	?	0.3	-19.5	9.8	11.1	3.7	3.5
S-EVA-18869	Sector IV T-132	25-35	F	1.4	-19.3	10.9	38.2	13.5	3.3
S-EVA-18870	Sector IV T-134	18-25	M	1.1	-18.6	10.9	26.2	9.4	3.2
S-EVA-18872	Sector IV T-136	18-25	?	1.5	-19.8	8.7	3.0	1.2	3.0
S-EVA-18873	Sector IV T-137	18-25	?	0.2	-19.5	9.3	26.3	8.9	3.4
S-EVA-18875	Sector IV T-140	25-35	F	0.3	-18.5	10.3	28.9	10.1	3.4

S-EVA-18876	Sector IV T-141	18-25	F	0.5	-19.1	10.1	32.9	11.2	3.4
S-EVA-18877	Sector IV T-142	18-25	?	0.4	-19.0	10.8	28.6	9.9	3.4
S-EVA-18878	Sector IV T-143	?	?	0.3	-19.3	10.5	36.6	12.2	3.5
S-EVA-18879	Sector IV T-144	10-15	?	1.2	-19.0	9.9	40.5	14.1	3.4
S-EVA-18880	Sector IV T-145	18-25	F?	1.0	-18.9	10.3	36.0	12.9	3.3
S-EVA-18881	Sector IV T-146	10-15	?	0.2	-19.3	10.3	25.6	8.7	3.4
S-EVA-18882	Sector IV T-147	10-15	?	1.5	-18.5	11.7	38.6	13.6	3.3
S-EVA-18883	Sector IV T-148	18-25	?	1.5	-18.9	10.3	35.5	12.6	3.3
S-EVA-18884	Sector IV T-149	18-25	?	0.4	-19.0	10.9	37.0	12.6	3.4
S-EVA-18885	Sector IV T-150	25-35	M	0.2	-19.0	10.8	23.1	8.0	3.4
S-EVA-18886	Sector IV T-151	5-10	?	0.3	-19.1	11.2	33.2	11.8	3.3
S-EVA-18887	Sector IV T-152	18-25	?	0.8	-18.8	10.8	30.4	10.8	3.3
S-EVA-18888	Sector IV T-153	?	?	0.9	-19.2	10.9	23.6	8.4	3.3
S-EVA-18889	Sector IV T-154	18-25	M	0.3	-19.0	11.1	38.5	13.5	3.3
S-EVA-18890	Sector IV T-155	18-25	M?	0.7	-8.6	10.2	33.3	12.1	3.3
S-EVA-18893	Sector IV T-158	18-25	F	0.5	-19.1	10.8	32.7	12.0	3.3
S-EVA-18894	Sector IV T-159	35-45	M	0.4	-19.0	10.2	30.1	10.7	3.4
S-EVA-18895	Sector IV T-239	?	?	0.3	-19.5	9.0	14.7	5.2	3.4
S-EVA-18898	Sector IV T-164	18-25	?	0.4	-19.0	10.6	35.8	13.5	3.4
S-EVA-18899	Sector IV T-165	10-15	?	0.4	-19.5	10.4	28.2	10.4	3.4
S-EVA-18900	Sector IV T-166	18-25	?	0.3	-19.7	11.0	31.1	11.1	3.5
S-EVA-18785	Sector II T-60	18-25	?	1.3	-	-	5.9	1.7	4.0
S-EVA-18824	Sector IV T-78	?	?	0.3	-	-	2.7	0.9	3.7
S-EVA-18871	Sector IV T-135	18-25	?	0.4	-	-	3.9	1.2	3.8
S-EVA-18896	Sector IV T-160	18-25	M?	0.1	-	-	11.0	2.4	5.4
S-EVA-18897	Sector IV T-163	18-25	F	1.6	-	-	40.5	11.4	4.3
S-EVA-18761	Sector I T-3	?	?	-	-	-	-	-	-
S-EVA-18772	Sector II T-45	25-35	?	-	-	-	-	-	-
S-EVA-18773	Sector II T-46	15-18	?	-	-	-	-	-	-
S-EVA-18774	Sector II T-47	?	?	-	-	-	-	-	-
S-EVA-18777	Sector II T-50	?	?	-	-	-	-	-	-
S-EVA-18778	Sector II T-51	18-25	M?	-	-	-	-	-	-
S-EVA-18780	Sector II T-53	18-25	?	-	-	-	-	-	-
S-EVA-18783	Sector II T-57	18-25	?	-	-	-	-	-	-
S-EVA-18784	Sector II T-59	?	?	-	-	-	-	-	-
S-EVA-18785	Sector II T-60	18-25	?	-	-	-	-	-	-
S-EVA-18789	Sector II T-64	25-35	?	-	-	-	-	-	-
S-EVA-18792	Sector II T-67	18-25	F?	-	-	-	-	-	-
S-EVA-18795	Sector II T-70	10-15	?	-	-	-	-	-	-
S-EVA-18798	Sector II T-73	18-25	?	-	-	-	-	-	-
S-EVA-18808	Sector III T-15	25-35	?	-	-	-	-	-	-
S-EVA-18811	Sector III T-18	18-25	M?	-	-	-	-	-	-
S-EVA-18815	Sector III T-22	18-25	?	-	-	-	-	-	-
S-EVA-18822	Sector III T-37	?	?	-	-	-	-	-	-
S-EVA-18825	Sector IV T-79	18-25	?	-	-	-	-	-	-
S-EVA-18827	Sector IV T-81	25-35	?	-	-	-	-	-	-
S-EVA-18834	Sector IV T-91	25-35	?	-	-	-	-	-	-
S-EVA-18840	Sector IV T-98	18-25	F	-	-	-	-	-	-

S-EVA-18845	Sector IV T-107	18-25	?	-	-	-	-	-	-
S-EVA-18874	Sector IV T-138	18-25	?	-	-	-	-	-	-
S-EVA-18891	Sector IV T-156	18-25	F?	-	-	-	-	-	-
S-EVA-18892	Sector IV T-157	?	?	-	-	-	-	-	-